APPENDIX T. LANDSCAPE LEVEL ISSUES FACING THE SOPN - CONCEPTUAL MODELS

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INTRODUCTION

In order to achieve a sustainable ecosystem within the parks of the Southern Plains Network (SOPN), management strategies will require not only an understanding of the natural resources available within each park, but also knowledge of the ecological and human-mediated processes occurring within the landscapes surrounding the parks. Neighboring land-use practices such as cattle grazing, row cropping, and development can severely alter the connection between the ecosystem inside and outside of the park (Turner et al. 2001). Managers must be aware of the possible ecological influences the surrounding landscape can have on the natural processes occurring in the park in order to make the management decisions that will perpetuate the ecological integrity (or desired condition, in the case of a cultural / historical site) of the park. A suite of conceptual models was created in order to address the landscape-level issues facing the parks of the SOPN. These models will be used to develop a set of vital signs that can be used to monitor land use changes occurring outside of the park and the influence of those changes on the park.

JENNY–CHAPIN MODELS (FIGURE 1)

Historically, the spatial configuration and species composition of a landscape (the *landscape pattern*) was created by the interaction of ecosystem processes (energy flow, trophic dynamics, etc…) acting upon a landscape over a long period of time (Turner et al. 2001). At global scale, these ecosystem processes are controlled by the interaction of five driving variables (termed *state factors*): climate, topography, parent material (geology), the potential biota, and time (Jenny 1941) (Figure 1A). Chapin et al. (1996) further modified the Jenny (1941) model to include four *interactive controls*: regional climate, soil resources, the major functional groups of organisms, and disturbance regime (Figure 1B). Interactive controls occur at a much more localized spatial and more recent temporal scale (e.g., the state factor climate refers to changes in global climates between a glacial and interglacial period (10,000 years), whereas regional climate could be the climate for a specific area (last 30 years), or a change in temperature or precipitation in a pasture before and after grazing (1 day). Interactive controls not only regulate ecosystem processes, but respond to these processes as well. This dynamic relationship between interactive controls and the landscape is what must be maintained in order to have a sustainable ecosystem (Chapin et al. 1996). Specific systems will react more strongly to some interactive controls (Chapin et al. 1996), for example, a grassland ecosystem / landscape is highly dependent on a frequent disturbance regime consisting of fire, migratory grazing, and drought (Krebs 2001).

Developing conceptual models for monitoring any ecological process requires precise definitions for spatial and temporal scales (Levin 1992). Different processes occur at very different spatial and temporal scales, for example a single fire event may occur in a 328 foot (100 m) area over a 2 day period, but the fire regime for the ecotype may occur in the same area over several hundred years (Delcourt et al. 1983). The spatial scale for these models included the lands surrounding the park and any processes, ecological or anthropogenic, which can affect those lands. The temporal scale of these models includes the next 50 – 100 years, as that time-frame is the most realistic for the monitoring goals of the SOPN.

CURRENT PROCESSES AFFECTING THE LANDSCAPE PATTERN (FIGURE 2)

Over the past 150 years, the ecological processes of the Southern Plains were disrupted by increased anthropogenic activity, which led to replacing the migratory bison (*Bison bison*) with non-migratory cattle, and large-scale fire suppression. As a result, the current landscape pattern of the SOPN is not only influenced by natural processes, but also heavily affected by human-mediated processes, and as the landscape pattern changes, it also influences both the natural and human processes.

HUMAN PROCESSES SUBMODEL (FIGURE 3)

Land cover patterns in the United States are mainly altered by direct human use (Meyer 1995). Four factors appear to be the major ecological stressors facing the SOPN (based on discussions with park managers, regional experts, surrounding land use and satellite imagery):

1) Residential development, which introduces housing developments, infrastructure (roads, sewers, power line easements, etc…)
2) Industrial / commercial developments, which introduces industrial and / or commercial buildings (along with the associated infrastructure)
3) Agricultural developments (e.g., cattle grazing, row cropping, and feedlots)
4) Management techniques of neighboring lands

These four stressors can affect the landscape pattern by altering the ecological process operating within the park, either by disrupting the natural disturbance regime or by modifying the habitat. These two variables are further explained in figures 5 and 8 below.

NATURAL DISTURBANCE REGIME (FIGURE 4)

Disturbance is an important part of many ecosystems and landscapes – disturbances create spatial heterogeneity and help maintain community structure (Turner et al. 2001). A disturbance is simply a discreet event, occurring over a short period of time, that disrupts the ecosystem and changes resource availability or the physical environment (White 1979). A disturbance regime refers to the spatial and temporal dynamics of disturbances over a longer time period (Turner et al. 2001).

EFFECTS OF CHANGING THE NATURAL DISTURBANCE REGIME (FIGURE 5)

Grassland ecosystems were maintained by a disturbance regime of grazing, fire, drought, and stochastic events like tornadoes, floods, and episodic infestations. Historically, the landscape was composed of a shifting mosaic of disturbed and undisturbed lands, however, as anthropogenic activity increased, this disturbance regime changed. Currently, the landscapes in the SOPN are less likely to undergo dramatic shifts in landscape pattern as a result of catastrophic events and global climate change and more likely to be affected by changes in the fire regime and grazing patterns. Therefore, these processes are shown in greater detail in figures 6 and 7.

Fire Submodel (Figure 6)

Fire is an important part of the disturbance regime of a grassland ecosystem (Smith and Smith 2001), and when it occurred naturally, it created a mosaic of burned and unburned patches across the landscape. Several land-managers have recognized the importance of fire and conducted prescribed fire on their lands, but these fires generally do not mimic historic conditions as burning occurs only on a pasture by pasture basis with a predictable frequency and often with different seasonality that would have historically occurred. Fire suppression has essentially removed fire as a regular disturbance in human-dominated landscapes, and as a result the landscape is dominated by competitively dominant plant species, which out compete the small-leafed and Nitrogen-fixing plants that colonize an area after a disturbance (Chapin et al. 1996). Fire suppression also increases the probability of woody encroachment, and also increases the fuel load of a landscape and both of which can contribute to a higher probability of a catastrophic fire.

Whenever a fire event does occur, there is an increased probability of colonization of invasive species (and woody encroachment if there is a long time period between fires). Once invasives have been established, the landscape can be exposed to edge effects (refer to fragmentation submodel for a detailed description of edge effects) between the burned and unburned lands, and the grassland may eventually be converted to a scrubland. If a catastrophic fire (a fire event at a large spatial scale) does occur, the dynamics of the native communities will be disrupted for a significant time (e.g., the Yellowstone fire).

The lack of fire within the grasslands of the SOPN can eventually affect the ecosystems of the parks and several indicators could be used to monitor these affects. Monitoring land-use / land-cover changes, in addition to the human population density in the surrounding areas, could be a good indicator of fire supression (e.g, the more people in an area, especially an urbanized region, the higher the probability of fire suppression). Also, as exotic species become more prevalent (due to fire supression), monitoring native grassland bird species (diversity and abundance) could indicate how fire suppression is affecting the system.

Grazing Submodel (Figure 7)

Grazing by migrating herds of bison stimulated primary production of the Plains grasslands by moving among patches of grazed and ungrazed habitat (Smith and Smith 2001). This pattern prevented extended overgrazing in any one area and helped create the shifting mosaic of vegetation historically found in the Southern Plains. Once the bison were replaced by cattle, this pattern changed. Domestic grazers are limited in their movements by fences and stable water sources and are generally kept at high densities, which can result in the overgrazing of the landscape (Figure 6A) (Smith and Smith 2001). This overgrazing can eliminate the beneficial effects the migratory grazing patterns of the bison had on the landscape (McNaughton 1993, Rambo and Faeth 1999).

Rotating cattle among pastures to prevent overgrazing of a specific pasture somewhat mimics the effects of migratory grazing by creating a mosaic of grazed and ungrazed pastures, but this only occurs on a small scale and is completely dependent on the management practices, and to some degree the economic conditions, of individual landowners. If cattle are not rotated, pastures become overgrazed and the probability of invasive species colonizing an area increases. Overgrazing can not only change the species composition of a landscape (Sims 1988), but also affect the spatial heterogeneity of the vegetation (Adler et al. 2001). Several grassland species are sensitive to heavy grazing pressures and will disappear from the landscape (Briske 1996). If grazing alters the spatial structure of a landscape, it will affect a wide range of ecosystems functions (Adler et al. 2001). For example, changes in spatial structure caused by grazing can alter the diversity of consumers utilizing the habitat (England and DeVos 1969, Grant et al. 1982). In addition, overgrazed lands have more exposed soil, which increases the amount of runoff. The increased nutrient load carried in the runoff would cause a disruption of the nutrient cycling occurring within the park.

Grazing (along with fire) is essential for maintaining a grassland ecosystem and therefore the effects of the grazing regimes in the lands surrounding the parks should be monitored. Establishing communication with the neighboring land owners and asking them about their herds and grazing rotations could be a good indicator of the processes occurring outside the park. Also, monitoring the land-use / land-cover changes, the number of fences, and change in species diversity along the borders of the park could assist park managers in determining where and how grazing is affecting the landscape.

HABITAT MODIFICATION (FIGURE 8)

Human mediated activities (stressors from Figure 3) can modify a landscape in myriad ways (Soulé 1986), however, the three major landscape-level issues resulting from habitat modification facing the parks in the SOPN are: 1) change in the ecosystem function, 2) change in the distribution of species, and 3) change in the habitat characteristics of the landscape.

Neighboring land use practices, such as overgrazing and row-cropping, can change the ecosystem processes occurring within the parks. High cattle densities and heavy agricultural use add higher concentrations of usable nitrogen, sulfates, and phosphates into the system, which will runoff into the park and disrupt the normal nutrient cycles. Industrial and residential development can introduce air- and water-borne pollutants, which will change the air and water quality of a park and both can affect ecological processes occurring within the park.

The distribution of species within a park is not only influenced by the management strategies of the park, but also neighboring land-use practices. If the habitat matrix surrounding the park is significantly modified (i.e., developed into neighborhoods, pastoral lands for grazing, row cropping, etc…), the composition of native species, changes (refer to the prairie dog sub-model under the grassland model section for an example of species displacement). Species requiring large expanses of unbroken habitat, like large carnivores, are displaced quickly and this causes a trophic shift within the food web. In the case of rare, threatened, or endangered (RTE) species (which generally have specific habitat requirements), habitat modification can be especially detrimental. If the park is the only area within the surrounding matrix possessing these unique habitat types, managers are faced with the problem of not only conserving this habitat type, but also monitoring the habitat for potential degradation, which can lead to the local extinction of the RTE species.

The landscape of the Southern Plains was traditionally composed of a continuously shifting mosaic of patches in varying stages of ecological succession. As the landscape became more human-dominated, this mosaic became fragmented, creating a matrix of native and non-native habitat types (refer to Figure 9 – Human-mediated fragmentation for a thorough description of fragmentation). As the landscape continued to be modified, the spatial configuration of the landscape changed. Currently, development has introduced patches of non-native pasture grasses for grazing, feedlots, row crops, and residential and commercial developments, all of which can introduce exotic species (refer to fragmentation submodel for a more thorough explanation of exotic species).

The effects of habitat modification are probably the biggest ecological threat facing the parks of the SOPN. However, the ecological effects for each of the three landscape level issues caused by habitat modification can be easily monitored.

The changes in ecosystem function can be monitored by measuring water and air quality within (or near) the parks. Sampling and measuring nutrient loads in the soils in and around the park could be possible indicators for the changes in nutrient cycling. Also, monitoring the human population density in areas surrounding the park (along with the rate of growth) could give park managers an idea of how the ecosystem will continue to change in the future.

Monitoring the changes in species distribution simply requires knowledge of the current distribution / abundance of the species in the park and the ability to monitor those species through time, using the same protocols. Maintaining a continuous inventory of every species in the park is not cost-effective, however, certain groups of species (native bird and amphibian communities) are good indicators of ecosystem integrity. Also, the presence (or disappearance) of populations of RTE species are good indicators of the community structure within an ecosystem.

The change in habitat characteristics can dramatically affect the landscape pattern. There are several indicators which can be used to monitor the change in habitat composistion: land-use / land-cover in areas surrounding the park, the mosaic of natural areas (patch size and arrangement), the amount of wetland within the region, and the density of houses can all be remotely sensed and are relative easy to monitor. As the habitat characteristics change, abundance and composition of exotic species will change across the landscape as well, so monitoring the diversity of exotic species within the park can be a good indicator of the processes occurring outside of the park.

Human-Mediated Fragmentation (Figure 9)

Fragmentation caused by human development is the biggest stressor currently occurring at the parks in the SOPN. Fragmentation of a landscape occurs when a large piece of habitat is transformed into a number of smaller patches, isolated from each other by a matrix of foreign habitats which are unlike the original (Wilcove et al. 1986). Fragmentation resulting from anthropogenic activity is generally irreversible and can severely disrupt ecosystem functions. The major effects of fragmentation are a decrease in the functional ecosystem size, a disruption of natural processes, and an increase in the amount of foreign habitat (patches of non-native habitat). These three effects are not independent and each facilitates the others, and any of these can cause more fragmentation (refer to Figures 5, 6, and 7 for a description of the possible effects of disrupting natural processes).

The size of the functional ecosystem decreases as the remaining patches of native habitat become surrounded by human developments (Krebs 2001). Species with large home ranges will become displaced, due to either an increase in human population (Parks and Harcourt 2002), or simply because their resources have decreased significantly (Wilcove et al. 1986). Large predators are especially vulnerable because their trophic position requires small population densities (Woodroffe and Ginsberg 1998) (refer to the prairie dog model for a detailed description of the trophic shifts occurring when a keystone predator is displaced). As the size of the functional ecosystem changes, resource availability changes as well. Species that were once able to forage a continuous piece of habitat will be forced to compete with other species for resources. Eventually, one species will out-compete the other, resulting in the local extinction of the competitively “weaker” species (Lotka 1925, Volterra 1926).

The connectivity among native patches decreases as the number of foreign patches within a habitat increases (Smith and Smith 2001). Essentially, each native patch becomes an island, separated from other native patches by an ocean of untraversable habitat types (Quammen 1996). Organisms generally leave their nascent area by eruptive migration, and patch isolation effectively prevents this exodus (Janzen 1986). Species are then restricted to small patches, and essentially become an isolated, small population, which will eventually lead to a decrease in genetic variability (through inbreeding and genetic drift) which is required to maintain a viable population (Freeman and Herron 1998). Decreased connectivity poses significant problems for species requiring two types of habitats, like amphibians which have both a terrestrial and aquatic stage in their life cycle and migratory birds which utilize multiple habitat types during their breeding and non-breeding seasons. If one of the required habitat types is destroyed or unreachable by migration, then the local extinction of that species is highly likely (Wilcove et al. 1986).

Edge effects are another ecological consequence of fragmentation. The edge is a border between two different habitat types (i.e., grassland and river, piñon-juniper and development). Edge effects are the ecological processes occurring at the margins, and these processes are very different from the processes occurring in the interior of the respective patches (Smith and Smith 2001). The ecological processes occurring at the margins are not limited to point of contact between the two habitat types. If there is a high edge to interior ratio, then the effects will affect the majority of the habitat type (Lovejoy et al. 1986).

Abiotic changes at the borders include a change in temperature and relative humidity, exposure to more wind, and an increase in the amount of solar radiation reaching the soil (Soulé 1986, Chapin et al. 1996). These abiotic factors will eventually change the soil chemistry, facilitating both the invasion of exotic plant species and woody encroachment (Soulé 1986).

The composition of species changes at the border between two habitat types. This area is easily colonized by species (both exotic and native) preferring edge habitat (Woodroffe and Ginsberg 1998). For example, feral cats (*Felis domesticus*) and dogs (*Canis familiarus*) frequent edge habitat, and these animals can facilitate the spread of zoonotic diseases, introduce parasites into the native vertebrate community, and decimate local population of small mammals, ground nesting birds, and herptiles. Native predators like raccoons (P*rocyon lotor*) also frequent edge habitat, further reducing the abundance of prey animals in the system. These factors change the viability of species residing at the margins – edge species experience an increase in viability and the viability of interior species decreases (Woodroffe and Ginsberg 1998).

Human-mediated fragmentation is often an irreversible and unstoppable process. The three immediate effects (decrease functional ecosystem size, disrupt natural processes, increase foreign habitat) interrupt the flow of energy across an ecosystem and will eventually increase the probability of extinction of species within the park. Monitoring these effects requires knowledge of the processes occurring inside and outside of the park. The mosaic of natural areas (patch size and arrangement) within the landscape surrounding the parks, and the connectivity between the patches can be used to indicate possible source and sink habitats surrounding the park. Land-cover / land-use patterns coupled with human population density can provide park managers with a wealth of knowledge concerning fragmentation outside of the parks. Monitoring the borders of the parks for a change in edge-friendly species (e.g, bird species which utilize edge habitat instead of interior habitat) as well as a change in exotic species composition can assist park managers in determining the edge effects occurring within the parks.

Monitoring the ecological effects of landscape dynamics is a difficult task for natural resource managers. The ecological processes affecting the landscape can occur at different spatial and temporal scales, depending on the process of interest. These conceptual models were developed in order to elucidate several of the major ecological processes affected by the ecosystem changes within SOPN. These models should assist park managers in choosing the appropriate vital signs for the monitoring program.

Human processes appear to be the major stressor on the environment, interrupting several key processes, like fire and grazing, that maintained the grassland ecosystem. Human development has also fragmented the landscape, which decreased the size of the functional ecosystem, reduced connectivity among native habitat patches, isolated species in small patches, and introduced edge effects across the landscape. These disruptive processes lower the fitness of native species residing in the park, which increases the probability of extinction within the park.

LITERATURE CITED

Adler, P. B., D. A. Raff, and W. K. Laurenroth. 2001. The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128:465-479.

Briske, D. D. 1996. Strategies of plant survival in grazed systems: a functional interpretation. Pages 37-68 *in* J. Hodgson and A. W. Illius, editors. The Ecology and Management of Grazing Systems. CAAB International, Wallingford Oxon, UK.

Chapin, F. S., M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. American Naturalist 148:1016-1037.

Delcourt, H. R., P. A. Delcourt, and T. Webb. 1983. Dynamic plant ecology: the spectrum of vegetational change in space and time. Quaternary Science Review 1:153-175.

England, R. E., and A. DeVos. 1969. Influence of animals on pristine conditions on the Canadian grasslands. Journal of Range Management 22:87-94.

Freeman, S., and J. C. Herron. 1998. Evolutionary Analysis. Prentice Hall, Upper Saddle River, New Jersey.

Grant, W. E., E. C. Birney, N. R. French, and D. M. Swift. 1982. Structure and productivity of grassland small mammal communities related to grazing induced changes in vegetative cover. Journal of Mammalogy 63:248-260.

Janzen, D. H. 1986. The eternal external threat. Pages 286-303 *in* M. E. Soulé, editor. Conservation Biology: the science and scarcity of diversity. Sinauer, Sunderland, MA.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill, New York.

Krebs, C. J. 2001. Ecology, 5th edition. Benjamin Cummings, San Francisco.

Levin, S. A. 1992. The problem of pattern and scale in ecology. Ecology 73:1943-1983.
Lotka, A. J. 1925. Elements of Physical Biology. Dover Publications, New York.
Lovejoy, T. E., R. O. Bierregaard, A. B. Rylands, J. R. Malcom, C. E. Quintela, L. H. Harper, K. S. Brown, A. H. Powell, G. N. Powell, H. O. Schubart, and M. B. Hays. 1986. Edge and other effects of isolation on Amazon forest fragments. Pages 257-285 *in* M. E. Soulé, editor. Conservation Biology: the science and scarcity of diversity. Sinauer Associates, Sunderland, MA.
McNaughton, S. J. 1993. Grasses and grazers, science and management. Ecological Applications 3:17-20.
Meyer, W. B. 1995. Past and present land use and land cover in the USA. Consequences 1995:25-33.
Parks, S. A., and A. H. Harcourt. 2002. Reserve size, local human density, and mammalian extinctions in U.S. protected areas. Conservation Biology 16:800-808.
Quammen, D. 1996. The Song of the Dodo: island biogeography in an age of extinction. Scribner, New York.
Rambo, J. L., and S. H. Faeth. 1999. Effect of vertebrate grazing on plant and insect community structure. Conservation Biology 13:1047-1054.
Sims, P. L. 1988. Grasslands. Pages 266-286 *in* M. G. Barbour and W. D. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, New York.
Smith, R. L., and T. M. Smith. 2001. Ecology and Field Biology, 6th edition. Benjamin Cummings, San Fransico.
Soulé, M. E. 1986. Conservation Biology: the science and scarcity of diversity. Sinauer, Sunderland, MA.
Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. Landscape ecology in theory and practice: pattern and process. Springer, New York.
Volterra, V. 1926. Fluctuations in the abundance of a species considered mathematically. Nature 118:558-560.
White, P. S. 1979. Pattern, process, and natural disturbance in vegetation. Botanical Review 45:229-299.
Wilcove, D. S., C. H. McLellan, and A. P. Dobson. 1986. Habitat fragmentation in the temperate zone. Pages 237-256 *in* M. E. Soulé, editor. Conservation Biology: the science and scarcity of diversity. Sinauer, Sunderland, MA.
Woodroffe, R., and J. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280:2126-2128.

Figure 1 – Jenny-Chapin Model (Chapin et al. 1996). Bold-type font indicates state factors, and italics indicate interactive controls. The circle represents the boundary of the ecosystem

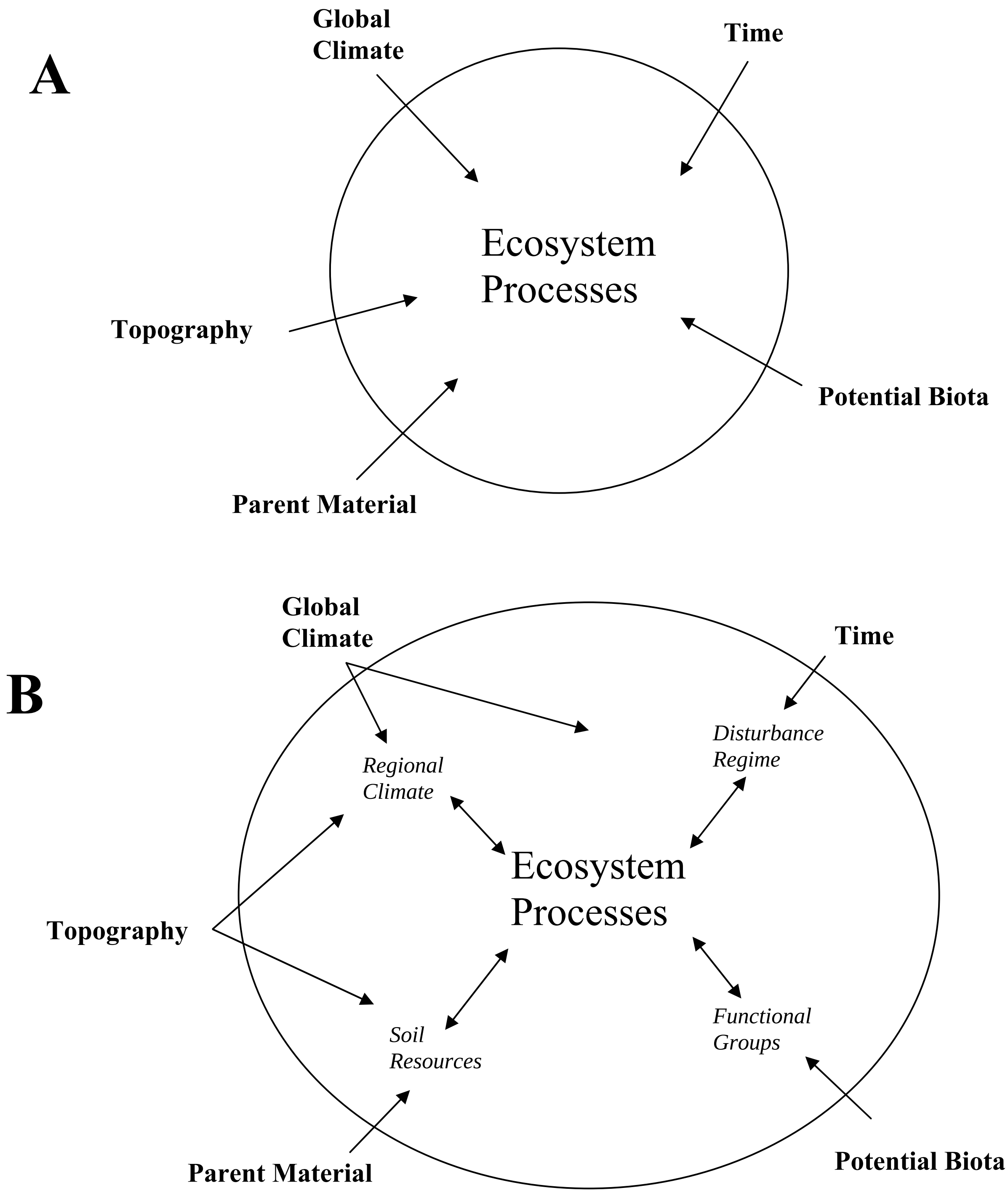


Figure 2 – Current processes creating landscape pattern. Ovals represent processes and patterns occurring within an ecosystem. Arrows represent the direction of influence – natural and human processes affect the landscape pattern, and as the landscape pattern changes it influences both natural and human processes.

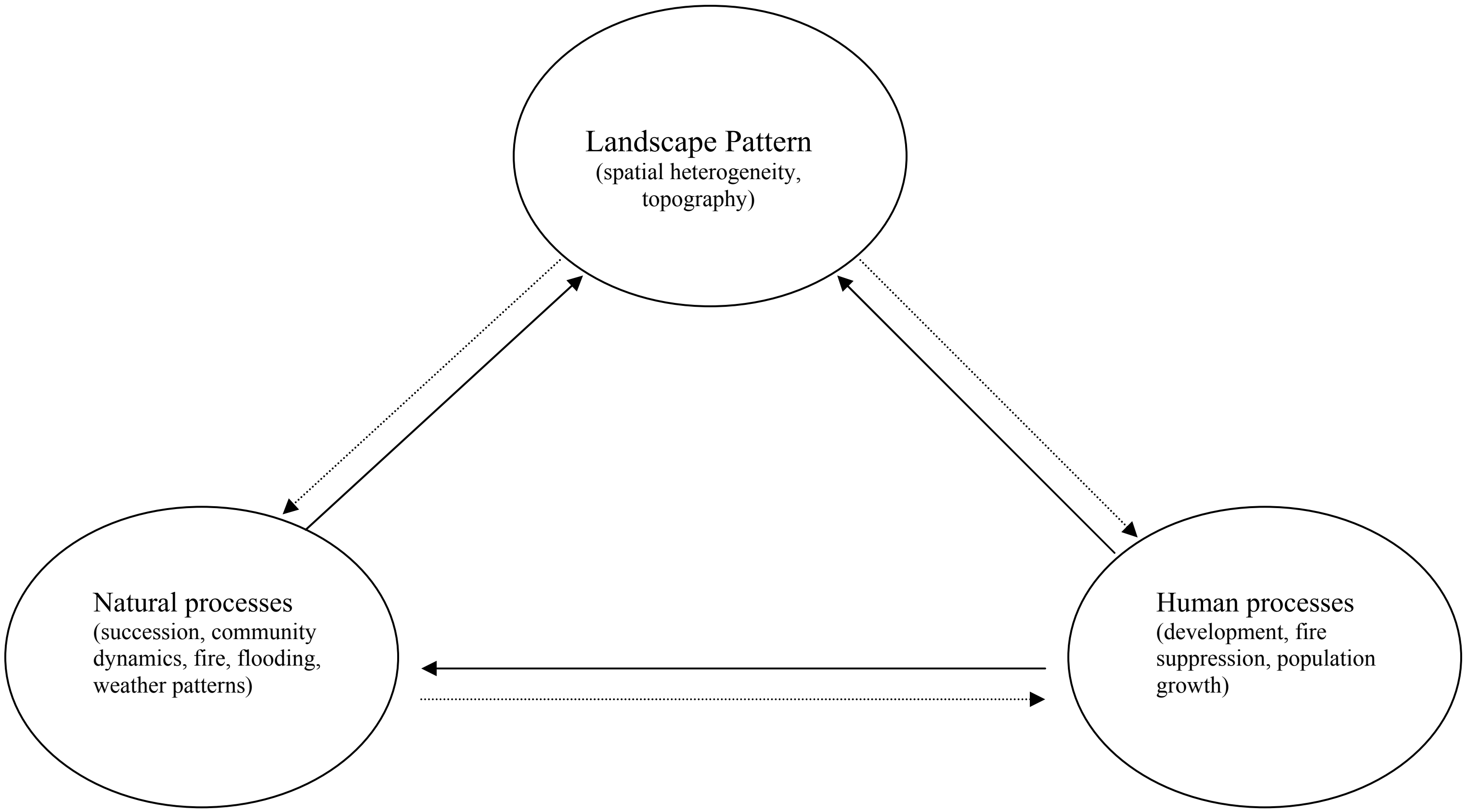


Figure 3 – Types of anthropogenic processes affecting the ecosystem processes and landscape pattern of the SOPN. Squares represent stressors. Ovals are variables representing ecological effects of development. Each stressor affects both the ecosystem processes and the landscape pattern. Δ represents 'change in.'

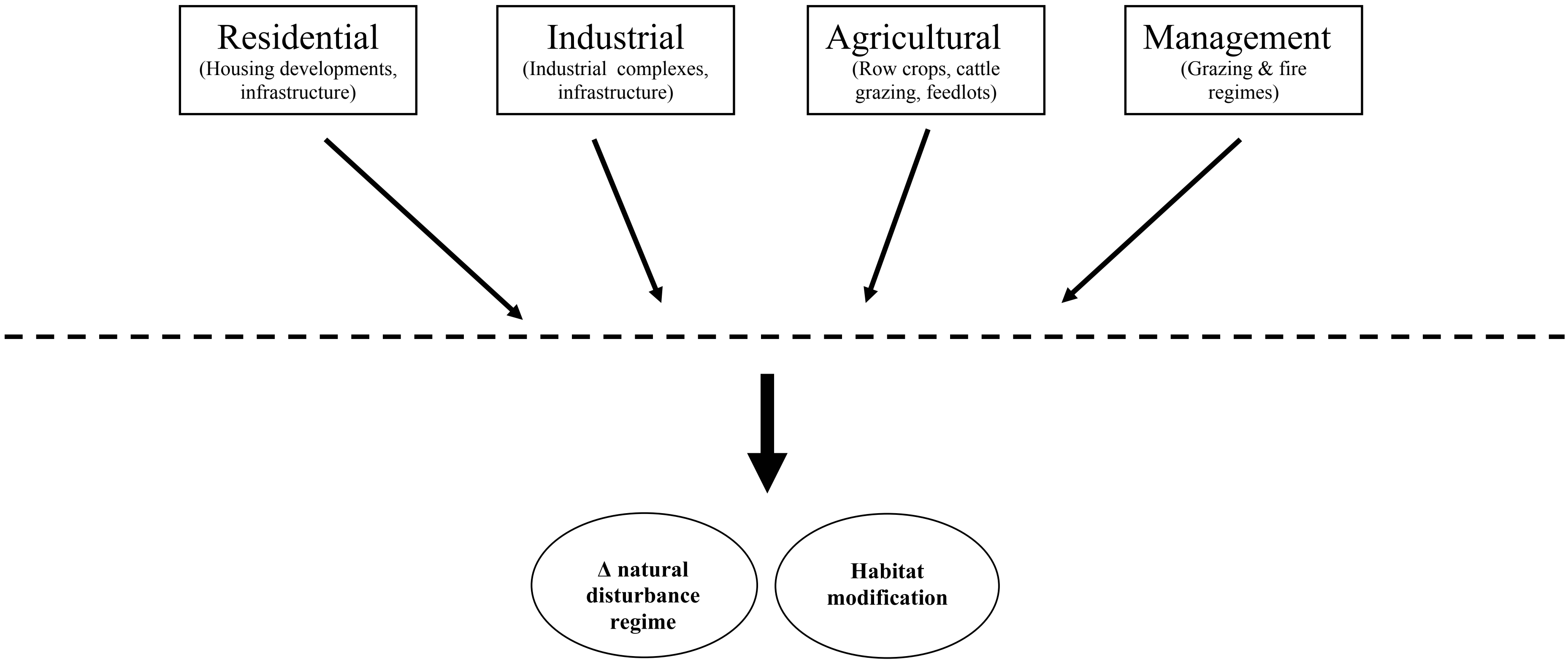


Figure 4 – Diagrammatic representation of a natural disturbance regime (modified from Chapin et al 1996). The arrows represent time between successive events.

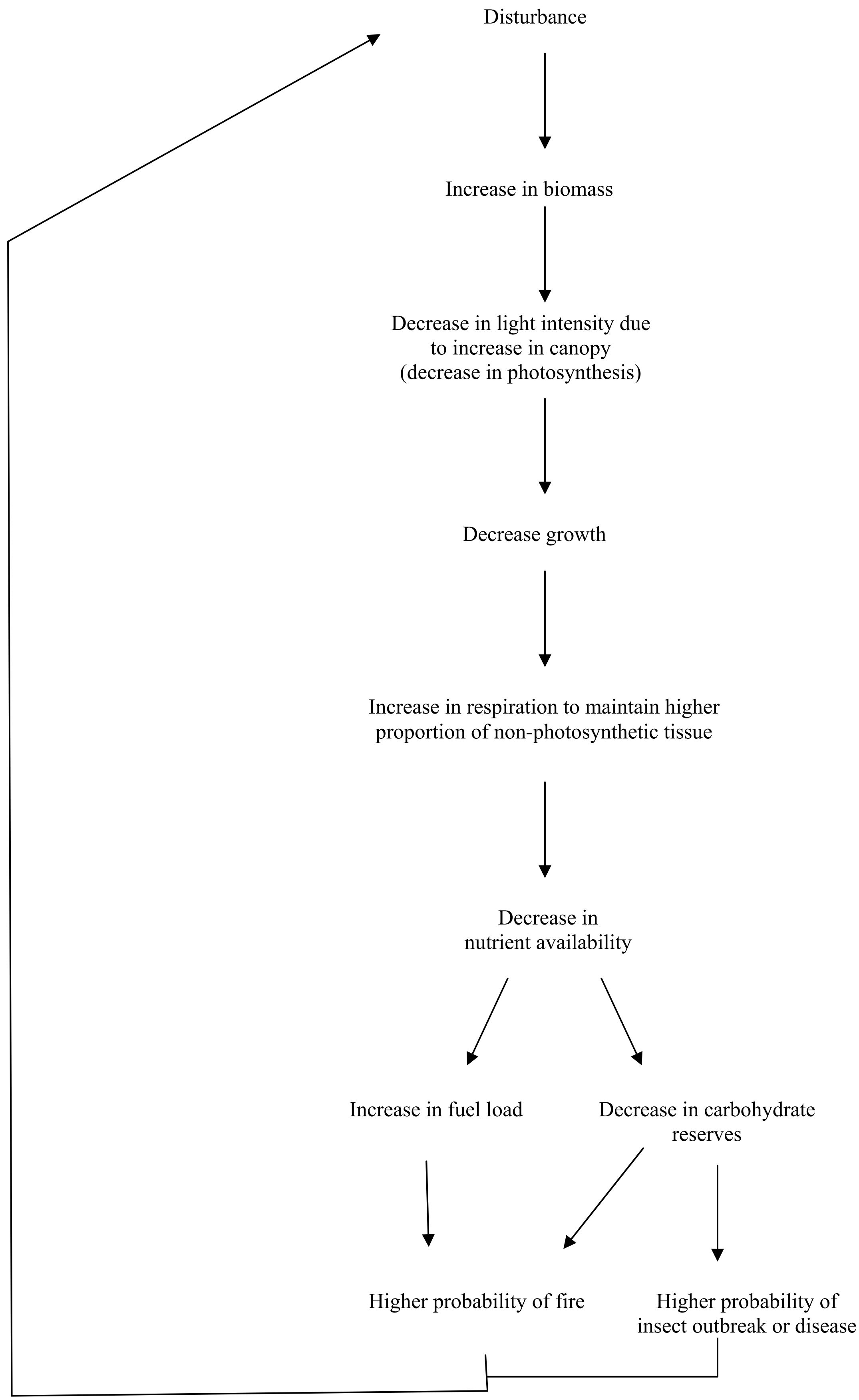


Figure 5 – Submodel representing the ecological processes affecting the landscape of the parks in the SOPN. Bold-type font indicates the presence of a separate submodel. Δ represents 'change in.'

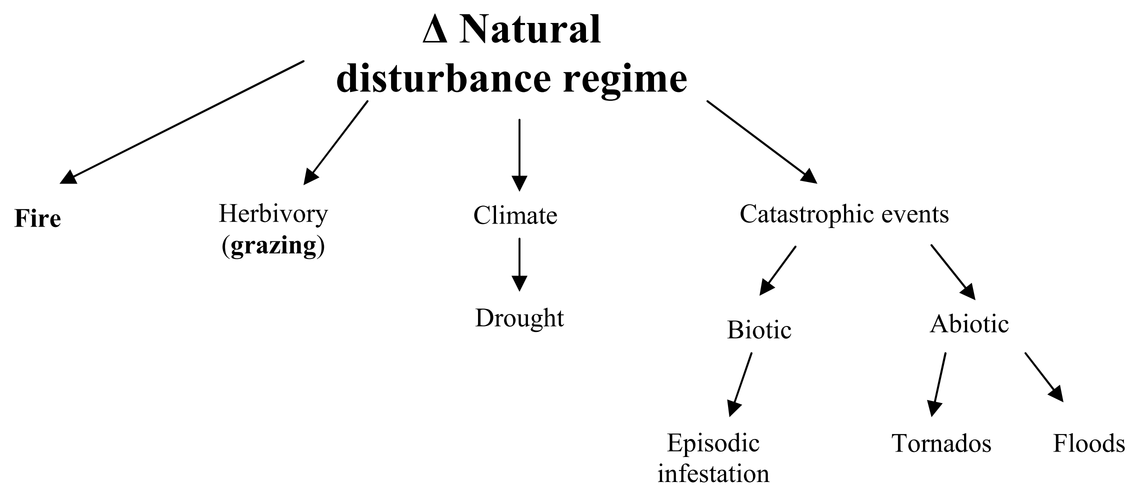


Figure 6 – A) Submodel representing effects of different fire management strategies on the landscape pattern of the SOPN. B) Submodel representing possible outcomes of a fire event in the SOPN.

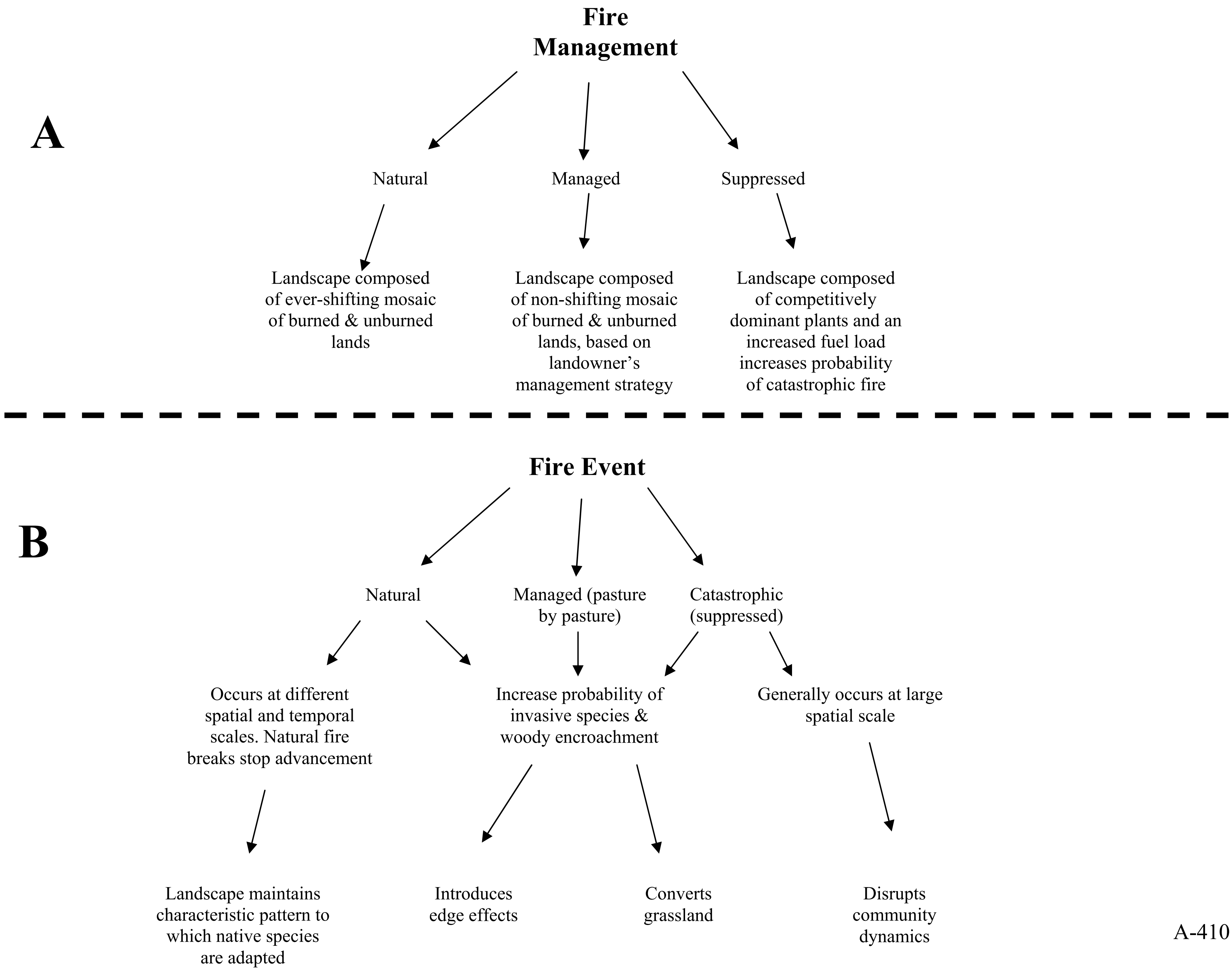
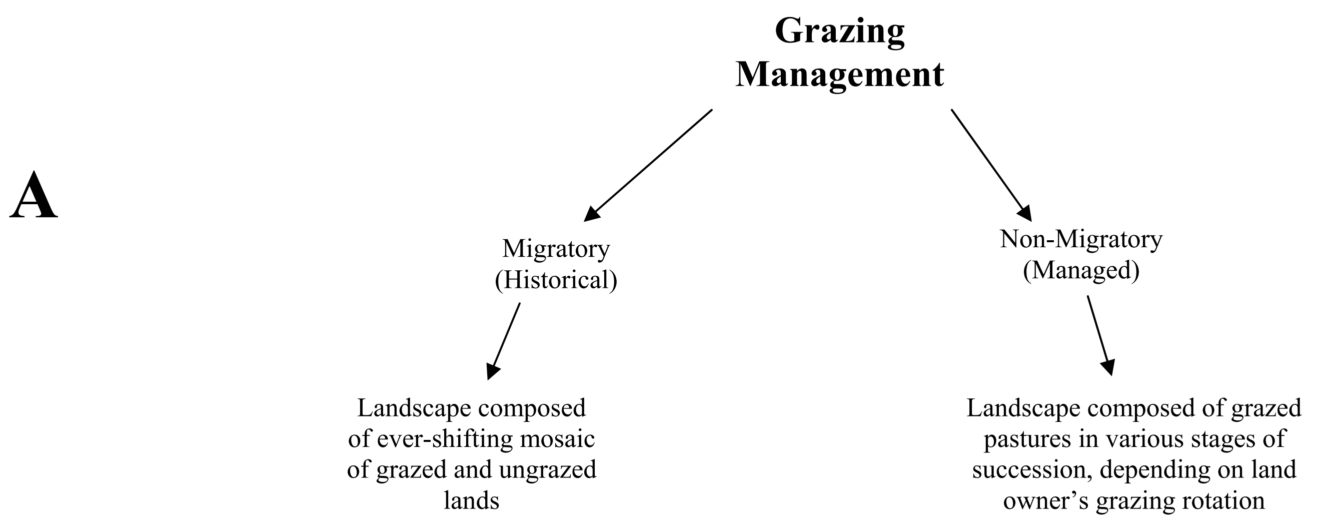


Figure 7 – A) Submodel contrasting the historical and current grazing regimes in the SOPN. B) Submodel representing possible effects of different grazing strategies used by land owners within the landscape of the SOPN. Δ represents 'change in.'



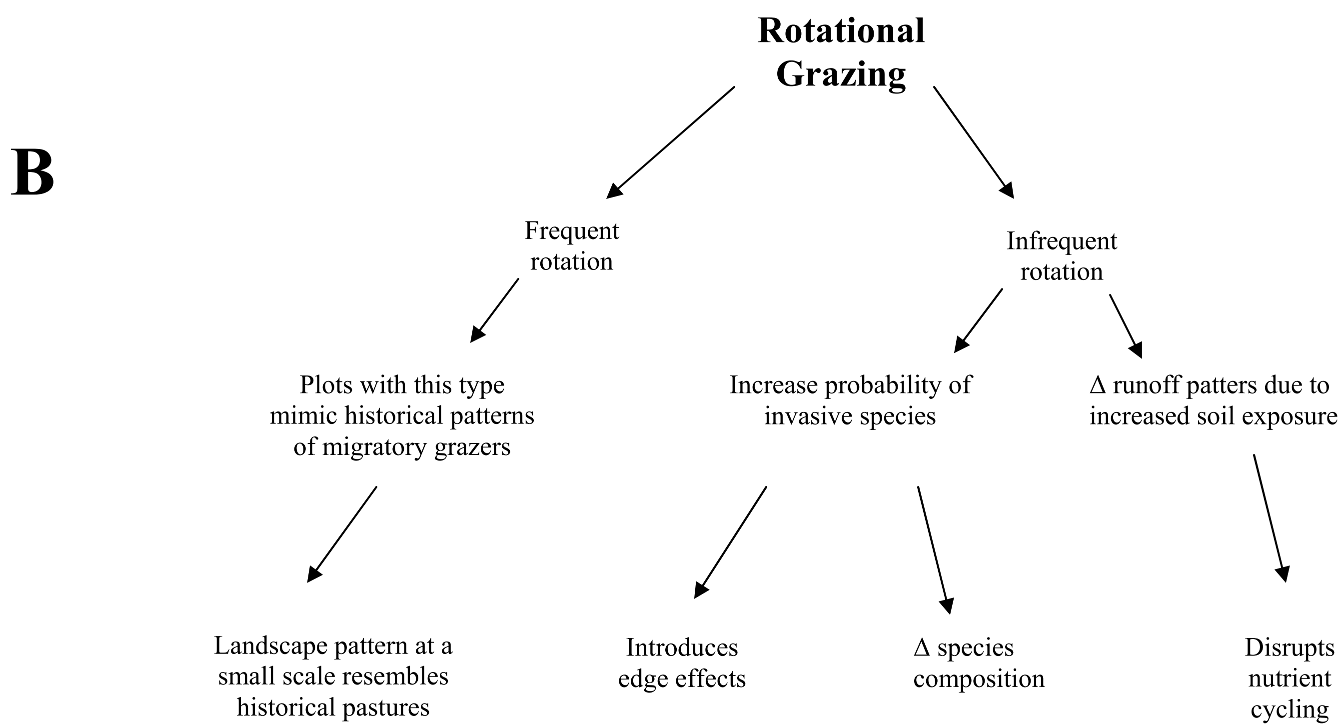


Figure 8 – Submodel representing the possible effects of human-mediated habitat modification on the landscapes within the SOPN. RTE represents rare, threatened and endangered species. Bold-type font indicates a separate submodel. Topics in italics are thoroughly addressed in the prairie dog model. Δ represents 'change in.'

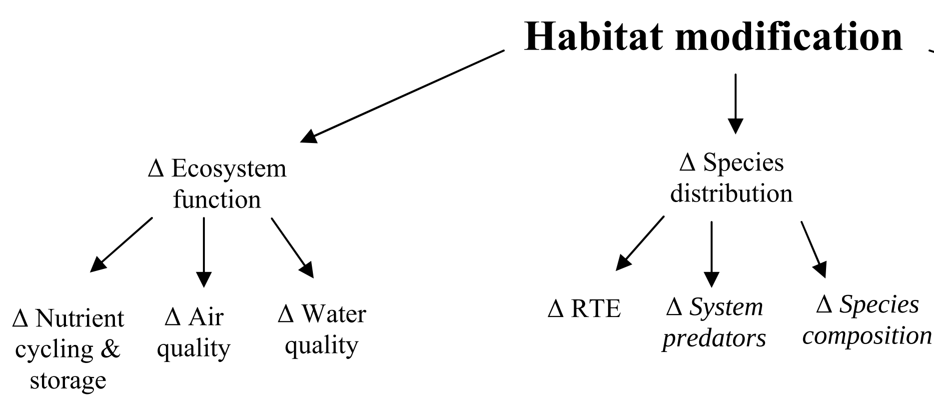


Figure 9 – Submodel representing the possible effects of human-mediated landscape-level fragmentation. Topics in italics are thoroughly addressed in the prairie dog model. Δ represents 'change in.'